

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
27 November 2003 (27.11.2003)

PCT

(10) International Publication Number  
**WO 03/097815 A2**

(51) International Patent Classification<sup>7</sup>: C12N  
(21) International Application Number: PCT/US03/16076  
(22) International Filing Date: 16 May 2003 (16.05.2003)  
(25) Filing Language: English  
(26) Publication Language: English  
(30) Priority Data:  
60/381,463 17 May 2002 (17.05.2002) US

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(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Declaration under Rule 4.17:**

— of inventorship (Rule 4.17(iv)) for US only

**Published:**

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **MOLECULAR IDENTIFICATION OF ASPERGILLUS SPECIES**

(57) Abstract: Novel techniques for the detection of *Aspergillus* in samples are disclosed. These techniques relate to PCR amplification and/or detection of *Aspergillus* ITS1 rDNA sequences, and the identification of particular species of *Aspergillus* by detecting differences in the ITS1-V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 nucleic acid sequences of *Aspergillus*. The highly variable regions of the ITS1 rDNA sequences are particularly useful in distinguishing, for example, *Aspergillus clavatus*, *Aspergillus granulatus*, *Aspergillus sydowii*, *Aspergillus flavipes*, *Aspergillus restrictus*, *Aspergillus versicolor*, *Aspergillus wentii*, and *Aspergillus chevalieri*. In particular embodiments, the sequence differences are also able to distinguish among variants of particular species, such as *Aspergillus granulatus* CBS 119.5A, *Aspergillus granulatus* strain NRRL 1932, *Aspergillus sydowii* strain NRRL 250, *Aspergillus sydowii* strain NRRL 4768, *Aspergillus sydowii* strain CUHI, *Aspergillus sydowii* strain CUH2, *Aspergillus sydowii* strain CUH7, and *Aspergillus sydowii* strain CUH8.

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## MOLECULAR IDENTIFICATION OF *ASPERGILLUS* SPECIES

### PRIORITY CLAIM

This application claims the benefit of U.S. Provisional Patent Application No. 60/381,463  
5 filed May 17, 2002.

### FIELD

This invention relates to methods for the detection and species identification of *Aspergillus*,  
and specifically to the use of internal transcribed spacer 1 (ITS1) nucleic acid sequences to identify or  
10 detect an *Aspergillus* species or strain of a species.

### BACKGROUND

Improvements in the management and treatment of debilitated medical and surgical patients  
have been accompanied by an unfortunate increase in the number of life-threatening infections due to  
15 pathogenic and opportunistic fungi (McNeil *et al.*, *Clin. Infect. Dis.* 33:641-47, 2001). AIDS, cancer  
chemotherapy and high dose corticosteroid treatment have all contributed to the increasing number of  
immunocompromised individuals. Many immunocompromised subjects develop opportunistic  
infections with saprophytic filamentous fungi, such as *Aspergillus* species, which are found in the  
environment and were originally considered to be of low virulence (Latge, *Clin. Microbiol. Rev.*  
20 12:310-50, 1999). These infections are often fulminant and fatal in immunocompromised patients.  
For example, pulmonary and cerebral aspergillosis have mortality rates of 86 and 99%, respectively,  
even when adequately treated (Denning, *Clin. Infect. Dis.* 23:608-14, 1996).

The advent of new, specific antifungal drugs and treatment regimes has improved the  
prospects for management of aspergillosis. However, diagnosis remains difficult, and early initiation  
25 of appropriate antifungal therapy is critical in reducing mortality rates in immunocompromised  
patients (Einsele *et al.*, *J. Clin. Microbiol.* 35:1353-60, 1997). Hence rapid diagnostic assays are  
needed to improve treatment outcomes.

*Aspergillus* is one of the primary pathogens which cause systemic fungal infection treated in  
hospitals. It usually affects subjects who have had organ transplants, acute leukemias and burns, and  
30 can be rapidly fatal if not diagnosed quickly. There are over 150 species of *Aspergillus* present in the  
soil, air and water, hence accurate detection of important species of *Aspergillus* is often complex and  
difficult.

Diagnosis of fungal infections is typically made by isolation of the infecting organism in  
culture, by serologic assays, or through histopathologic examination of tissue (Hamilton, *Med. Mycol.*  
35 36:351-64, 1998). Isolation of *Aspergillus* species in culture can require several days for adequate  
growth and sporulation to occur, delaying appropriate drug therapy, and a positive culture may  
represent benign colonization rather than true invasion or infection (de Repentigny, *Clin. Infect. Dis.*

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14:S11-22, 1992). When histopathology is performed on tissue sections, the morphological similarities of the various *Aspergillus* species can make definitive species identification difficult.

Alternatively, serological tests can be used to diagnose fungal infections, but most such tests lack the desired sensitivity and/or specificity for a confident diagnosis. Serologic tests on a single serum sample to detect circulating fungal antigens may be inconclusive, and antibody production in the immunocompromised patient population most at risk for invasive aspergillosis is often variable and an unreliable diagnostic indicator (Morrison and Lindsley, *Fungal Pathogenesis: Principles and Practice*, Marcel Dekker, Inc., 667-716, 2001).

Current serological assays do not identify *Aspergillus* to the species level, and are both time-consuming and expensive. In addition, *Aspergillus terreus* has been shown to be resistant to amphotericin B, the most commonly prescribed drug for treating invasive aspergillosis. *Aspergillus fumigatus* has been reported to develop resistance to itraconazole. Thus, there remains a need for a rapid test to identify aspergilli to the species level, to help assist in the selection of appropriate drugs for the treatment of clinical *Aspergillus* infections. Fungal species identification may also be important for detecting organisms in the environment that may be potentially pathogenic, for example to an immunocompromised person who is exposed to that environment.

PCR-based methods of detection, which show promise as rapid techniques to diagnose infections, have been used in the identification of DNA from *Candida* and *Aspergillus* species. However, most of these tests are only genus specific, and are unable to specifically identify many clinically and environmentally important *Aspergillus* species.

Unique internal transcribed sequence 2 (ITS2) coding regions have been used to develop nucleic acid probes for several different species of *Aspergillus* (*A. flavus*, *A. fumigatus*, *A. niger*, *A. terreus*, and *A. nidulans*), as disclosed in U.S. Patent No. 6,372,430, which is incorporated by reference.

## SUMMARY

A novel approach to species identification of a fungus is disclosed herein. In one embodiment, the method takes advantage of the finding that the ITS1 of fungal ribosomal DNA is not well conserved across these species. The present inventors have found that different species of *Aspergillus* have much higher non-conserved regions of the rDNA ITS1 nucleic acid sequence than of the rDNA ITS2 region that has been used for species identification in the past. This surprising finding has permitted the development of a much more specific method of detecting different species of *Aspergillus*, by taking advantage of these sequence differences in ITS1. Particular *Aspergillus* species that can be detected with this method include, but are not limited to, *A. clavatus*, *A. granulosus*, *A. sydowii*, *A. flavipes*, *A. restrictus*, *A. versicolor*, *A. wentii*, *A. chevalieri*, and *A. ustus*, or any combination or sub-set of these species (such as *A. granulosus*, *A. clavatus*, and *A. sydowii*).

Certain of the sequences disclosed herein are novel sequences. In a particular embodiment, an isolated nucleic acid molecule includes SEQ ID NO: 1 (from *A. clavatus*), SEQ ID NO: 2 and SEQ ID NO: 3 (from *A. granulosus*), and SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID

NO: 7, SEQ ID NO: 8 and SEQ ID NO: 9 (from *A. sydowii*), or a nucleotide sequence with at least 75% (for example at least 85% or at least 95%) sequence identity to the nucleotide sequence of SEQ ID NO: 1 (from *A. clavatus*), SEQ ID NO: 2 and SEQ ID NO: 3 (from *A. granulosis*), and SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8 and SEQ ID NO: 9 (from *A.*  
 5 *sydowii*), wherein the nucleotide sequence is from a member of the genus *Aspergillus*, such as *clavatus*, *granulosus*, or *sydowii* species.

In another embodiment, an isolated nucleic acid molecule includes a nucleotide sequence set forth as SEQ ID NO: 10, 11 or 12 (from *A. flavipes*) or a degenerate variant thereof, SEQ ID NO: 13 or 14 (from *A. restrictus*) or a degenerate variant thereof, SEQ ID NO: 15, 16, 17 or 18 (from *A.*  
 10 *versicolor*) or a degenerate variant thereof, or SEQ ID NO: 19 (from *A. wentii*) or a degenerate variant thereof, wherein the nucleotide sequence identifies a member of the genus *Aspergillus* as a member of *flavipes*, *restrictus*, *versicolor*, or *wentii* species.

In yet another embodiment, an isolated nucleic acid molecule includes a nucleotide sequence selected from the group consisting of at least 15 consecutive nucleotides of a nucleotide sequence  
 15 with at least 75% (for example at least 85% or at least 95%) sequence identity to the nucleic acid sequence shown in SEQ ID NO: 1, at least 15 consecutive nucleotides of a nucleotide sequence with at least 75% (for example at least 85% or at least 95%) sequence identity to the nucleic acid sequence shown in SEQ ID NO: 2 or 3, and at least 15 consecutive nucleotides of a nucleotide sequence with at least 75% (for example at least 85% or at least 95%) sequence identity to the nucleic  
 20 acid sequence shown in SEQ ID NO: 4, 5, 6, 7, 8 or 9.

In one embodiment, an isolated nucleic acid molecule includes a nucleotide sequence selected from the group consisting of at least 15 consecutive nucleotides of the nucleic acid sequence shown in SEQ ID NO: 10, 11 or 12 or a degenerate variant thereof, at least 15 consecutive  
 25 nucleotides of the nucleic acid sequence shown in SEQ ID NO: 13 or 14 or a degenerate variant thereof, and at least 15 consecutive nucleotides of the nucleic acid sequence shown in SEQ ID NO: 15, 16, 17 or 18 or a degenerate variant thereof.

In a further embodiment, a method is disclosed for detecting the presence of an *Aspergillus* species in a biological sample, for example by distinguishing one species from another by detecting differences in the ITS1 region of the fungal rRNA. Since it has now been found that the ITS1 region  
 30 is particularly poorly conserved across these different species, detection of sequence differences in this region is a particularly sensitive and specific approach to identifying the different species. In particular examples, the method includes detecting differences in two or more (for example at least three or all five) of ITS1-V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 nucleic acid sequences of  
 35 *Aspergillus*. The differences can be detected, for example, by sequencing the two or more nucleic acid sequences, or using nucleic acid probes specific for those sequences. The target sequences may be amplified prior to detecting the distinguishing nucleic acid sequences.

In particular disclosed embodiments, the method distinguishing among *Aspergillus* *granulosus*, *ustus*, *sydowii*, *versicolor* and *nidulans*, and in addition can be used to distinguish among *Aspergillus clavatus*, *flavipes*, *restrictus*, *wentii*, and *chevalieri*.

Examples of the sequences that distinguish the species are:

(a) SEQ ID NO: 1 or a degenerate variant thereof to identify *Aspergillus clavatus*;

(b) SEQ ID NO: 2, SEQ ID NO: 3 or a degenerate variant thereof to identify

*Aspergillus granulatus*;

5 (c) SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, SEQ ID NO: 9, or a degenerate variant thereof to identify *Aspergillus sydowii*.

The variability of the ITS1 V1-5 regions even permits differentiation among strains of the species. For example, it is possible to distinguish between *Aspergillus granulatus* CBS 119.5A and NRRL 250, and among *Aspergillus sydowii* iNRRL, CUH1, CUH2, CUH7 and CUH8.

10 Other examples of sequences that differentiate the species by distinguishing the ITS1-V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 nucleotide sequences are

(a) SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12 or a degenerate variant thereof to identify *A. flavipes*;

(b) SEQ ID NO: 13, SEQ ID NO: 14 or a degenerate variant thereof to identify *A.*

15 *restrictus*

(c) SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, SEQ ID NO: 18 or a degenerate variant thereof to identify *A. versicolor*;

(d) SEQ ID NO: 19 or a degenerate variant thereof to identify *A. wentii*.

(e) SEQ ID NO: 20, SEQ ID NO: 21 or a degenerate variant thereof to identify *A.*

20 *chevalieri*.

In a particular example, the method involves amplifying an *Aspergillus* species ITS1 region including a region having a nucleotide sequence with at least 75% (for example at least 85% or at least 95%) sequence identity to SEQ ID NO: 1, a nucleotide sequence with at least 75% (for example at least 85% or at least 95%) sequence identity to SEQ ID NOs: 2 and 3, and/or a nucleotide sequence with at least 75% sequence identity to SEQ ID NOs: 4-9, and sequencing the ITS1 region, thereby determining the presence of the *Aspergillus* species. Alternatively, the method includes amplifying an *Aspergillus* species ITS1 region selected from the group consisting of SEQ ID NO: 1, SEQ ID NOs: 2 and 3, and/or SEQ ID NOs: 4-9, and sequencing the ITS1 region, thereby determining the presence of the *Aspergillus* species.

In another embodiment, a method is disclosed for detecting the presence of an *Aspergillus* species in a biological sample, by amplifying an *Aspergillus* species ITS1 region selected from the group consisting of SEQ ID NO: 10, 11 and 12 or a degenerate variant thereof, SEQ ID NOs: 13 and 14 or a degenerate variant thereof, SEQ ID NOs: 15-18 or a degenerate variant thereof, SEQ ID NO: 19 or a degenerate variant thereof, and SEQ ID NOs: 20 and 21 or a degenerate variant thereof, and sequencing the ITS1 region, thereby determining the presence of the *Aspergillus* species.

In a further embodiment, a method is disclosed for detecting the presence of an *Aspergillus* species in a biological sample, by amplifying an *Aspergillus* species ITS1 region using oligonucleotide primers comprising at least 15 consecutive nucleotides of an ITS1 region selected

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from the group consisting of SEQ ID NO: 1, SEQ ID NO: 2 and 3, SEQ ID NO: 4, 5, 6, 7, 8, and 9, SEQ ID NO: 10, 11 and 12, SEQ ID NO: 13 and 14, SEQ ID NO: 15, 16, 17 and 18, SEQ ID NO: 19, and SEQ ID NO: 20 and 21, and sequencing the ITS1 region, thereby determining the presence of the *Aspergillus* species.

5 In yet a further embodiment, a method is disclosed for detecting the presence of an *Aspergillus* species in a biological sample, by amplifying an *Aspergillus* species ITS1 region using universal fungal primers ITS5 (SEQ ID NO: 28), ITS1 (SEQ ID NO: 31), ITS2 (SEQ ID NO: 29), and ITS4 (SEQ ID NO: 30), followed by hybridization with oligonucleotide probes comprising at least 15 consecutive nucleotides of an ITS1 region selected from the group consisting of SEQ ID NO: 1, SEQ ID NO: 2 and 3, SEQ ID NO: 4, 5, 6, 7, 8 and 9, SEQ ID NO: 10, 11 and 12, SEQ ID NO: 13 and 14, SEQ ID NO: 15, 16, 17, 18, SEQ ID NO: 19, and SEQ ID NO: 20 and 21, with detection of hybridization indicating the presence of the *Aspergillus* species.

Kits for carrying out these methods are also disclosed.

These and other embodiments are disclosed in the detailed description of this specification.  
15 Other features and advantages of the disclosed methods will become apparent from a review of the following detailed description of the disclosed embodiments and the appended claims.

#### BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a diagram of fungal rDNA. Hybridization sites for the ITS5 and ITS1  
20 amplification primers are shown in the phylogenetically conserved 18S region, hybridization sites for the ITS2 and ITS3 amplification primers are shown in the phylogenetically conserved 5.8S region, and the hybridization site for the ITS4 amplification primer is shown in the phylogenetically conserved 28S region. Arrows designate the direction of amplification.

Figure 2 is an alignment of ITS1 sequences of representative *Aspergillus* species and strains.  
25 Dots symbolize identical nucleotides compared to the *A. niger* I sequence; dashes indicate alignment gaps. Aligned sequences are separated by horizontal lines according to their phylogenetic relationship (Samson and Pitt (eds.), *Integration of Modern Taxonomic Methods for Penicillium and Aspergillus Classification*, Harwood Academic Publishers, 2000) and represent the following strains: *A. niger* I (ATCC 1015, ATCC 64028), *A. niger* II (ATCC 16404), *A. flavus* (ATCC 11497, ATCC 34896, ATCC 44310, ATCC 64025), *A. parasiticus* (ATCC 56775), *A. tamarii* (ATCC 64841), *A. flavipes* I (ATCC 11013), *A. flavipes* II (ATCC 16805), *A. flavipes* III (ATCC 24487), *A. candidus* (NRRL 303, NRRL 312), *A. terreus* (ATCC 1012, ATCC 10029, ATCC 7860), *A. chevalieri* (ATCC 16443, ATCC 24546), *A. restrictus* (NRRL 148, NRRL 151), *A. fumigatus* (ATCC 16903, CDC 2570), *A. granulatus* (CBS 119.5A, NRRL 1932), *A. ustus* I (ATCC 14417), *A. ustus* II (ATCC 16801), *A. ustus* III (CUH4), *A. ustus* IV (NRRL 275), *A. ustus* V (NRRL 5077, CUH5), *A. sydowii* I (NRRL 250, NRRL 4768, CUH1, CUH2, CUH8), *A. sydowii* II (CUH7), *A. versicolor* I (ATCC 10072, NRRL 238, NRRL 239), *A. versicolor* II (CUH3), *A. nidulans* I (ATCC 16855, ATCC 64027), and *A. nidulans* II (CDC 040487).  
35

## SEQUENCE LISTING

The nucleic sequences listed in the accompanying sequence listing are shown using standard letter abbreviations for nucleotide bases, as defined in 37 C.F.R. 1.822. Only one strand of each nucleic acid sequence is shown, but the complementary strand and the corresponding RNA sequences of both strands are understood to be included by any reference to the displayed strand.

SEQ ID NO: 1 shows the nucleic acid sequence of the ITS1 region of *A. clavatus* (strain ATCC 9192).

SEQ ID NO: 2 shows the nucleic acid sequence of the ITS1 region of *A. granulosis* (strain CBS 119.5A).

SEQ ID NO: 3 shows the nucleic acid sequence of the ITS1 region of *A. granulosis* (strain NRRL 1932).

SEQ ID NO: 4 shows the nucleic acid sequence of the ITS1 region of *A. sydowii* (strain NRRL 250).

SEQ ID NO: 5 shows the nucleic acid sequence of the ITS1 region of *A. sydowii* (strain NRRL 4768).

SEQ ID NO: 6 shows the nucleic acid sequence of the ITS1 region of *A. sydowii* (strain CUH1).

SEQ ID NO: 7 shows the nucleic acid sequence of the ITS1 region of *A. sydowii* (strain CUH2).

SEQ ID NO: 8 shows the nucleic acid sequence of the ITS1 region of *A. sydowii* (strain CUH7).

SEQ ID NO: 9 shows the nucleic acid sequence of the ITS1 region of *A. sydowii* (strain CUH8).

SEQ ID NO: 10 shows the nucleic acid sequence of the ITS1 region of *A. flavipes* (strain ATCC 11013).

SEQ ID NO: 11 shows the nucleic acid sequence of the ITS1 region of *A. flavipes* (strain ATCC 16805).

SEQ ID NO: 12 shows the nucleic acid sequence of the ITS1 region of *A. flavipes* (strain ATCC 24487).

SEQ ID NO: 13 shows the nucleic acid sequence of the ITS1 region of *A. restrictus* (strain NRRL 148).

SEQ ID NO: 14 shows the nucleic acid sequence of the ITS1 region of *A. restrictus* (strain NRRL 151).

SEQ ID NO: 15 shows the nucleic acid sequence of the ITS1 region of *A. versicolor* (strain ATCC 10072).

SEQ ID NO: 16 shows the nucleic acid sequence of the ITS1 region of *A. versicolor* (strain NRRL 238).

SEQ ID NO: 17 shows the nucleic acid sequence of the ITS1 region of *A. versicolor* (strain NRRL 239).

SEQ ID NO: 18 shows the nucleic acid sequence of the ITS1 region of *A. versicolor* (strain CUH3).

5 SEQ ID NO: 19 shows the nucleic acid sequence of the ITS1 region of *A. wentii* (strain 3650).

SEQ ID NO: 20 shows the nucleic acid sequence of the ITS1 region of *A. chevalieri* (strain ATCC 16443).

10 SEQ ID NO: 21 shows the nucleic acid sequence of the ITS1 region of *A. chevalieri* (strain ATCC 24546).

SEQ ID NO: 22 shows the nucleic acid sequence of the ITS1 region of *A. ustus* (strain ATCC 14417).

SEQ ID NO: 23 shows the nucleic acid sequence of the ITS1 region of *A. ustus* (strain ATCC 16801).

15 SEQ ID NO: 24 shows the nucleic acid sequence of the ITS1 region of *A. ustus* (strain NRRL 275).

SEQ ID NO: 25 shows the nucleic acid sequence of the ITS1 region of *A. ustus* (strain NRRL 5077).

20 SEQ ID NO: 26 shows the nucleic acid sequence of the ITS1 region of *A. ustus* (strain CUH4).

SEQ ID NO: 27 shows the nucleic acid sequence of the ITS1 region of *A. ustus* (strain CUH5).

SEQ ID NO: 28 shows the nucleic acid sequence of fungal universal forward primer ITS5.

SEQ ID NO: 29 shows the nucleic acid sequence of fungal universal reverse primer ITS2.

25 SEQ ID NO: 30 shows the nucleic acid sequence of fungal universal reverse primer ITS4.

SEQ ID NO: 31 shows the nucleic acid sequence of fungal universal forward primer ITS1.

SEQ ID NO: 32 shows the nucleic acid sequence of fungal universal forward primer ITS3.

SEQ ID NO: 33 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

30 SEQ ID NO: 34 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 35 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

35 SEQ ID NO: 36 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 37 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 38 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 39 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 40 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

5 SEQ ID NO: 41 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 42 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

10 SEQ ID NO: 43 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 44 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 45 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

15 SEQ ID NO: 46 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 47 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

20 SEQ ID NO: 48 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 49 shows the nucleic acid sequence of an exemplary *A. granulosis* ITS1 primer/probe.

SEQ ID NO: 50 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

25 SEQ ID NO: 51 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

SEQ ID NO: 52 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

30 SEQ ID NO: 53 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

SEQ ID NO: 54 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

SEQ ID NO: 55 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

35 SEQ ID NO: 56 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

SEQ ID NO: 57 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

SEQ ID NO: 58 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

SEQ ID NO: 59 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

5 SEQ ID NO: 60 shows the nucleic acid sequence of an exemplary *A. nidulans* ITS1 primer/probe.

SEQ ID NO: 61 shows the nucleic acid sequence of an exemplary *A. ustus* ITS1 primer/probe.

10 SEQ ID NO: 62 shows the nucleic acid sequence of an exemplary *A. ustus* ITS1 primer/probe.

SEQ ID NO: 63 shows the nucleic acid sequence of an exemplary *A. ustus* ITS1 primer/probe.

SEQ ID NO: 64 shows the nucleic acid sequence of an exemplary *A. ustus* ITS1 primer/probe.

15 SEQ ID NO: 65 shows the nucleic acid sequence of an exemplary *A. ustus* ITS1 primer/probe.

SEQ ID NO: 66 shows the nucleic acid sequence of an exemplary *A. ustus* ITS1 primer/probe.

20 SEQ ID NO: 67 shows the nucleic acid sequence of an exemplary *A. ustus* ITS1 primer/probe.

## DETAILED DESCRIPTION

### I. Explanation of Terms

Unless otherwise noted, technical terms are used according to conventional usage.

25 Definitions of common terms in molecular biology may be found in Benjamin Lewin, *Genes VII*, published by Oxford University Press, 1999; Kendrew *et al.* (eds.), *The Encyclopedia of Molecular Biology*, published by Blackwell Science Ltd., 1994; and Robert A. Meyers (ed.), *Molecular Biology and Biotechnology: a Comprehensive Desk Reference*, published by VCH Publishers, Inc., 1995.

30 As used herein, the singular forms "a," "an," and "the," refer to both the singular as well as plural, unless the context clearly indicates otherwise. Similarly, the word "or" is intended to include "and" unless the context clearly indicates otherwise. Also, as used herein, the term "comprises" means "includes." Hence "comprising A or B" means including A, B, or A and B. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

35 In order to facilitate review of the various embodiments of the invention, the following explanations of specific terms are provided:

**Amplification:** of a nucleic acid molecule (e.g., a DNA or RNA molecule) refers to use of a technique that increases the number of copies of a nucleic acid molecule in a sample. An example of amplification is polymerase chain reaction (PCR), in which a sample is contacted with a pair of oligonucleotide primers under conditions that allow for the hybridization of the primers to a nucleic

acid template in the sample. The primers are extended under suitable conditions, dissociated from the template, re-annealed, extended, and dissociated to amplify the number of copies of the nucleic acid. The product of amplification can be characterized by electrophoresis, restriction endonuclease cleavage patterns, oligonucleotide hybridization or ligation, and/or nucleic acid sequencing using standard techniques.

The PCR method can be modified in certain embodiments. For example, a polymerase chain reaction-enzyme immunoassay (PCR-EIA) method can be used for amplification and differentiation of fungi. The PCR-EIA method is described in Elie *et al.*, *J. Clin. Microbiol.* 36:3260-65, 1998, and can be modified to suit particular embodiments.

Other examples of amplification include strand displacement amplification, as disclosed in U.S. Patent No. 5,744,311; transcription-free isothermal amplification, as disclosed in U.S. Patent No. 6,033,881; repair chain reaction amplification, as disclosed in WO 90/01069; ligase chain reaction amplification, as disclosed in EP-A-320,308; gap filling ligase chain reaction amplification, as disclosed in 5,427,930; and NASBA RNA transcription-free amplification, as disclosed in U.S. Patent No. 6,025,134.

**Animal:** A living multi-cellular vertebrate or invertebrate organism, a category that includes, for example, mammals and birds. The term mammal includes both human and non-human mammals. Similarly, the term "subject" includes both human and veterinary subjects.

**cDNA (complementary DNA):** A piece of DNA lacking internal, non-coding segments (introns) and transcriptional regulatory sequences. cDNA also may contain untranslated regions (UTRs) that are responsible for translational control in the corresponding RNA molecule. cDNA is synthesized in the laboratory by reverse transcription from messenger RNA extracted from cells.

**Degenerate variant:** A "degenerate variant" of a probe or primer includes sequences that have altered nucleic acid sequences, but retain their ability to bind to the target sequences (and identify or amplify the fungal target) with sufficient specificity. In some particular examples, no more than about 1, 2, 5, or 10 nucleic acids are changed, or the probe or primer retains at least 80%, 85%, 90%, or 95% sequence identity to the original sequence. Degenerate variants also include probe or primer sequences to which additional sequence has been added, while still retaining the noted specificity of the probe or primer.

A "degenerate variant" or "minor variant" of an *Aspergillus* ITS1 sequence includes sequences that have altered nucleic acid sequences, but retain their ability to identify particular *Aspergillus* species. In some particular examples, no more than about 1, 2, 5, or 10 nucleic acids are changed.

**Fungus:** Living, single-celled and multicellular organisms belonging to the kingdom Fungi. Most species are characterized by a lack of chlorophyll and presence of chitinous cell walls, and some fungi may be multinucleated. In one embodiment, a fungus is an *Aspergillus* species. Representative, non-limiting examples of *Aspergillus* include the species listed in Table I below, such as *A. chevalieri*, *A. clavatus*, *A. flavipes*, *A. granulosis*, *A. restrictus*, *A. sydowii*, *A. ustus*, *A. versicolor*, and *A. wentii*.

**Homolog:** A nucleotide sequence that shares a common ancestor with another nucleotide sequence; the homologs diverged when a species carrying that ancestral sequence split into two species.

**Isolated:** An "isolated" microorganism (such as a fungus) has been substantially separated or purified away from microorganisms of different types, strains, or species. For example, a colony of *Aspergillus clavatus* would be considered an "isolated" *Aspergillus clavatus*. Microorganisms can be isolated by a variety of techniques, including serial dilution and culturing.

An "isolated" biological component (such as a nucleic acid molecule or protein) has been substantially separated or purified away from other biological components in the cell of the organism in which the component naturally occurs. The term "isolated" does not require absolute purity. Nucleic acids and proteins that have been "isolated" include nucleic acids and proteins purified by standard purification methods. The term also embraces nucleic acids and proteins prepared by recombinant expression in a host cell, as well as chemically synthesized nucleic acids.

**ITS1:** The first internal transcribed spacer sequence of fungal rDNA. As illustrated in Figure 1, a diagram of the fungal rDNA region, the ITS1 sequence is located between the 18S and 5.8S coding sequences. The ITS1 region varies from approximately 142 to 187 nucleotides in length depending upon the species examined. In one embodiment, the nucleotides in the ITS1 sequence can be numbered beginning with the first nucleotide downstream of the 18S coding sequence and ending with the last nucleotide directly in advance of the 5.8S coding sequence.

The hypervariable regions of ITS1 are defined as follows with reference to Figure 2: ITS1-V1, position 8-30 (12-21 nucleotides in length); ITS1-V2, position 50-67 (13-14 nucleotides in length); ITS1-V3, position 81-141 (12-54 nucleotides in length); ITS1-V4, position 151-181 (23-28 nucleotides in length); and ITS1-V5, position 192-215 (17-21 nucleotides in length). Compared to the ITS1-V3 sequence of *A. niger* (54 nucleotides), notably shorter corresponding sequences were found for *A. chevalieri* (12 nucleotides), *A. granulatus* (21 nucleotides), *A. ustus* (21-30 nucleotides), *A. sydowii* (22 nucleotides), *A. versicolor* (22 nucleotides), and *A. nidulans* (21-22 nucleotides).

**Oligonucleotide:** A linear polynucleotide sequence of between 5 and 100 nucleotide bases in length.

**Operably linked:** A first molecule, such as a nucleic acid or protein, is operably linked with a second molecule when the first molecule is placed in a functional relationship with the second molecule. For instance, a promoter is operably linked to a nucleic acid coding sequence if the promoter affects the transcription or expression of the coding sequence. Additionally, an intron is operably linked to an exon for the function of splicing. Generally, operably linked nucleotide sequences are contiguous and, where necessary to join two protein-coding regions, in the same reading frame.

**ORF (open reading frame):** A series of nucleotide triplets (codons) coding for amino acids without any internal termination codons. These sequences are usually translatable into a peptide.

**Probes and primers:** Nucleic acid probes and primers can be readily prepared based on the nucleic acid molecules provided in this invention, and therefore provide a substantial utility for the

disclosed sequences. A probe comprises an isolated nucleic acid capable of hybridizing to a template nucleic acid, and a detectable label or reporter molecule can be attached to a probe. Typical labels include radioactive isotopes, enzyme substrates, co-factors, ligands, chemiluminescent or fluorescent agents, haptens, and enzymes. Methods for labeling and guidance in the choice of labels appropriate for various purposes are discussed in, for example, Sambrook *et al.*, *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory Press, 2001; and Ausubel *et al.* (eds.), *Short Protocols in Molecular Biology*, John Wiley and Sons, 1999.

Primers are short nucleic acid molecules, for example DNA oligonucleotides 15 nucleotides or more in length. Primers can be annealed to a complementary target DNA strand by nucleic acid hybridization to form a hybrid between the primer and the target DNA strand, and the primer can be extended along the target DNA strand by a DNA polymerase enzyme. Primer pairs can be used for amplification of a nucleic acid sequence, *e.g.*, by PCR or other nucleic acid amplification methods.

Methods for preparing and using probes and primers are described, for example, in Sambrook *et al.*; Ausubel *et al.* (eds.); and Innis *et al.*, *PCR Applications, Protocols for Functional Genomics*, Academic Press, Inc., 1999. PCR primer pairs can be derived from a known sequence, for example, by using computer programs intended for that purpose such as Primer3, Whitehead Institute for Biomedical Research, Cambridge, MA; the program is accessible through the Whitehead Institute's website.

The specificity of a particular probe or primer increases with its length. Thus, as one non-limiting example, a primer comprising 15 consecutive nucleotides of the *A. clavatus* ITS1 sequence will anneal to a target sequence, such as another ITS1 homolog from the family contained within an *A. clavatus* genomic DNA library, with a higher specificity than a corresponding primer of only 10 nucleotides. Thus, in order to obtain greater specificity, probes and primers can be selected that comprise 20, 25, 30, 35, 40, 50, 75, 100, or more consecutive nucleotides of *A. clavatus* ITS1 sequence. The present disclosure thus includes isolated nucleic acid molecules (probes and primers) that comprise specified lengths of a fungal ITS1 sequence. Such molecules can comprise at least 10, 20, 25, 30, 35, 40, 50, 75, or 100 consecutive nucleotides of the ITS1 sequence, and can be obtained from any region of the ITS1 sequence.

Any of the probes or primers disclosed herein can also be of a maximum length, for example no more than 15, 25, 30, 40, 50, 75 or 100 nucleotides in length.

**Recombinant:** A recombinant nucleic acid is one that has a sequence that is not naturally occurring or has a sequence that is made by an artificial combination of two otherwise separated segments of sequence. This artificial combination can be accomplished by chemical synthesis or, more commonly, by the artificial manipulation of isolated segments of nucleic acids, *e.g.*, by genetic engineering techniques.

**Sample:** Encompasses a sample obtained from an animal, plant, or the environment. An "environmental sample" includes a sample obtained from inanimate objects or reservoirs within an indoor or outdoor environment, including, but not limited to: soil, water, dust, and air samples.

**Biological sample:** A sample obtained from a plant or animal subject. As used herein, biological samples include all clinical samples useful for detection of fungal infection in subjects, including, but not limited to, cells, tissues, and bodily fluids, such as blood, derivatives and fractions of blood (such as serum); biopsied or surgically removed tissue, including tissues that are unfixed, frozen, or fixed in formalin or paraffin; tears; milk; skin scrapes; surface washings; urine; sputum; cerebrospinal fluid; prostate fluid; pus; bone marrow aspirates; bronchoalveolar lavage (BAL); and saliva. In particular embodiments, the biological sample is obtained from an animal subject, such as blood, serum, cerebrospinal fluid, BAL, pus, or a skin lesion..

**Sequence identity:** The similarity between two nucleic acid sequences, is expressed in terms of the similarity between the sequences, otherwise referred to as sequence identity. Sequence identity is frequently measured in terms of percentage identity, similarity, or homology; a higher percentage identity indicates a higher degree of sequence similarity. Homologs of fungal ITS1 sequences will possess a relatively high degree of sequence identity when aligned using standard methods.

The NCBI Basic Local Alignment Search Tool (BLAST), Altschul *et al.*, *J. Mol. Biol.* 215:403-10, 1990, is available from several sources, including the National Center for Biotechnology Information (NCBI, Bethesda, MD), for use in connection with the sequence analysis programs blastp, blastn, blastx, tblastn and tblastx. It can be accessed through the NCBI website. A description of how to determine sequence identity using this program is also available on the website.

When less than the entire sequence is being compared for sequence identity, homologs will typically possess at least 75% sequence identity over short windows of 10-20 amino acids, and can possess sequence identities of at least 85% or at least 90% or 95% depending on their similarity to the reference sequence. Methods for determining sequence identity over such short windows are described on the NCBI website..

These sequence identity ranges are provided for guidance only; it is entirely possible that strongly significant homologs could be obtained that fall outside of the ranges provided.

An alternative indication that two nucleic acid molecules are closely related is that the two molecules hybridize to each other under stringent conditions. Stringent conditions are sequence-dependent and are different under different environmental parameters. Generally, stringent conditions are selected to be about 5 °C to 20 °C lower than the thermal melting point (T<sub>m</sub>) for the specific sequence at a defined ionic strength and pH. The T<sub>m</sub> is the temperature (under defined ionic strength and pH) at which 50% of the target sequence hybridizes to a perfectly matched probe. Conditions for nucleic acid hybridization and calculation of stringencies can be found in Sambrook *et al.*; and Tijssen, *Hybridization With Nucleic Acid Probes, Part I: Theory and Nucleic Acid Preparation*, Laboratory Techniques in Biochemistry and Molecular Biology, Elsevier Science Ltd., 1993. Nucleic acid molecules that hybridize under stringent conditions to a fungal ITS1 sequence will typically hybridize to a probe based on either an entire ITS1 sequence or selected portions of the ITS1 sequence under wash conditions of 2x SSC at 50 °C.

**Transformed:** A transformed cell is a cell into which a nucleic acid has been introduced by molecular biology techniques. The term "transformation" encompasses all techniques by which a

nucleic acid molecule might be introduced into such a cell, including transfection with viral vectors, transformation with plasmid vectors, and introduction of naked DNA by electroporation, lipofection, and particle gun acceleration.

5       **Vector:** A nucleic acid molecule as introduced into a host cell, thereby producing a transformed host cell. A vector can include nucleic acid sequences that permit it to replicate in a host cell, such as an origin of replication. A vector can also include one or more selectable marker genes and other genetic elements.

10       This disclosure provides a simple, rapid, and useful method for differentiating species of *Aspergillus* from one another, and from other environmentally, clinically or medically important fungi.

15       This approach is made possible by providing the ITS1 nucleotide sequences of several clinically important species of *Aspergillus*. Fungal DNA can be amplified using primers, such as universal fungal primers (for example universal primers ITS1, ITS2, ITS3, ITS4, or ITS5). The different species of *Aspergillus* are then differentiated by taking advantage of the ITS1 sequence differences between these species and between different sequevars of a species. For example, the amplified fungal DNA can be sequenced in a high speed sequencer, such that sequence differences between the different *Aspergillus* species are associated with a particular species of *Aspergillus* from which the sequence was obtained.

20       While the ITS1 sequences of some *Aspergillus* species were previously known, the sequences of many others disclosed herein are novel sequences that were not previously available to distinguish different *Aspergillus* species from one another. The sequences (and the complement) of the sequences claimed in this disclosure, along with any modifications to these sequences, may be utilized in assays for the identification of fungi based on several existing methodologies, as well as future improvements and alterations of this technology. These techniques include, but are not limited to, assays based on hybridization, ligation, polymerization, depolymerization, sequencing, chemical degradation, enzymatic digestion, electrophoresis, chromatography and amplification.

25       In addition to the 27 different ITS1 sequences (SEQ ID NOs: 1-27) of clinically important *Aspergillus* species and sequevars thereof, also provided are the sequences of several universal fungal primers (SEQ ID NOs: 28-32) that can be used to amplify the *Aspergillus* nucleic acid, prior to species or sequevars identification by the nucleic acid differences disclosed herein.

30       Those versed in the art will recognize that specification of a single-stranded DNA sequence implies the utility of the complementary DNA sequence, as well as the two equivalent RNA sequences, for detecting species or strain differences. Furthermore, sequences incorporating modifications of any of the moieties comprising the nucleic acid (such as the sugar or the backbone) are functional equivalents of the sequence. These sequences (or subsequences thereof) can themselves serve as probes or primers.

## II. *Aspergillus* Sequences

The disclosure provides isolated ITS1 nucleic acid molecules from *Aspergillus* species, which can be used for the detection and species identification of *Aspergillus*. The disclosure encompasses isolated ITS1 nucleic acid molecules from *A. clavatus*, *A. granulosis*, *A. sydowii*, *A. flavipes*, *A. restrictus*, *A. versicolor*, *A. wentii*, *A. chevalieri*, and *A. ustus*. Specific nucleic acid molecules include:

### *A. clavatus* (strain ATCC 9192):

CCGAGTGC GGGCCCTCTGGGTCCAACCTCCCACCCGTGTTTATCGTACCTTGTTGCTTCG  
10 GCGGGCCCGCCGTCTTCGGACGGCCGCGGGGAGGCCTCCGCGCCCCCGGGCCCGCGCC  
CGCCGAAGACCACAACATGAACTCTGTTCTGAAGTTTGCAGTCTGAGTTGATTATCATA  
ATCAGTTA (SEQ ID NO: 1).

### *A. granulosis* (strain CBS 119.5A):

CCGAGTGCAGGTCTGCCCCTGGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCAAC  
15 GTTGCTTCGGCGGTGCGCCCCTCCGGGGGCAGCCGCGGAGACCACACCGAACCTCTTG  
TTTAAGCCTGTTGTCTGAGCTTGATAGCAAATCTATTA (SEQ ID NO: 2).

### *A. granulosis* (strain NRRL 1932):

CCGAGTGCAGGTCTGCCCCTGGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCAAC  
20 GTTGCTTCGGCGGTGCGCCCCTCCGGGGGCAGCCGCGGAGACCACACCGAACCTCTTG  
TTTAAGCCTGTTGTCTGAGCTTGATAGCAAATCTATTA (SEQ ID NO: 3).

### *A. sydowii* (strain NRRL 250):

CTGAGTGC GGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGAATACCTAACACTGTTGC  
25 TTCGGCGGGGAACCCCTCGGGGGCGAGCCGCGGGGACTACTGAACTTCATGCCTGAG  
AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 4).

### *A. sydowii* (strain NRRL 4768):

CTGAGTGC GGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGAATACCTAACACTGTTGC  
30 TTCGGCGGGGAACCCCTCGGGGGCGAGCCGCGGGGACTACTGAACTTCATGCCTGAG  
AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 5).

### *A. sydowii* (strain CUH1):

CTGAGTGC GGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGAATACCTAACACTGTTGC  
35 TTCGGCGGGGAACCCCTCGGGGGCGAGCCGCGGGGACTACTGAACTTCATGCCTGAG  
AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 6).

*A. sydowii* (strain CUH2):

CTGAGTGC GGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGAATACCTAACACTGTTGC  
TTCGGCGGGGAACCCCTCGGGGGCGAGCCGCCGGGGACTACTGAACTTCATGCCTGAG  
AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 7).

5

*A. sydowii* (strain CUH7):

CTGAGTGC GGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGAATACCTAACACTGTTGC  
TTCGGCGGGGAGCTCCCTCGGGGGCGAGCCGCCGGGGACTACTGAACTTCATGCCTGAG  
AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 8).

10

*A. sydowii* (strain CUH8):

CTGAGTGC GGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGAATACCTAACACTGTTGC  
TTCGGCGGGGAACCCCTCGGGGGCGAGCCGCCGGGGACTACTGAACTTCATGCCTGAG  
AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 9).

15

*A. flavipes* (strain ATCC 11013):

CCGAGTGAGGGTCTCGTGGCCCAACCTCCCACCCGTGACTACTGTACCACTGTTGCTTC  
GGCGGGCCCGCCAGCGTCCGCTGGCCGCCGGGGGGCTTCTGCCCCCGGGCCCGTGCCCCG  
CCGAGACCCCAACACGAACACTGTTTCTGAAAGCCTGTATGAATTCGATTCTTTGTAAT  
CAGTTA (SEQ ID NO: 10).

20

*A. flavipes* (strain ATCC 16805):

CCGAGTGAGGGTCTCGTGGCCCAACCTCCCACCCGTGACTACTGTACCACTGTTGCTTC  
GGCGGGCCCGCCAGCCTAGCTGGCCGCCGGGGGGCTTCTGCCCCCGGGCCCGTGCCCCG  
CGGAGACCCCAACACGAACACTGTTTCTGAAAGCCTGTATGAATCCGATTCTTTGTAATC  
AGTTA (SEQ ID NO: 11).

25

*A. flavipes* (strain ATCC 24487):

CCGAGTGAGGGTCTCGTGGCCCAACCTCCCACCCGTGACTACTGTACCACTGTTGCTTC  
GGCGGGCCCGCCAGCGCCCGCTGGCCGCCGGGGGGCTTCTGCCCCCGGGCCCGTGCCCCG  
CCGAGACCCCAACACGAACACTGTTTCTGAAAGCCTGTATGAATCCGATTCTTTGTAAT  
CAGTTA (SEQ ID NO: 12).

30

*A. restrictus* (strain NRRL 148):

CCGAGTGCGGGCCCTCTGGGTCCAACCTCCCATCCGTGTCTCTTGTAACCTGTTGCTTCG  
GCGGGCCCGCCTTCATGGCCGCCGGGGGGCTTCTGCCCCCGGGCCCGTGCCCCGCGGGAG  
ACTCCAACATTGAACACTGTCTGAAGGTTGCAGTCTGAGTTTTTCATATAAGAAAAATCGT  
TA (SEQ ID NO: 13).

35

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*A. restrictus* (strain NRRL 151):

CCGAGTGCGGGCCCTCTGGGTCCAACCTCCCATCCGTGTCTCTGTACCCTGTTGCTTCG  
GCGGGCCCGCCTTCATGGCCGCCGGGGGGCTTCTGCCCCGGGGCCCGCGCCCGCCGGAG  
ACTCCAACATTGAACACTGTCTGAAGGTTGCAGTCTGAGTTTTCATATAAGAAAAATCGT  
5 TA (SEQ ID NO: 14).

*A. versicolor* (strain ATCC 10072):

CTGAGTGCGGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGACTACCTAACACTGTTGC  
TTCGGCGGGGAGCCCTCTCGGGGGCGAGCCGCCGGGGACTACTGAACTTCATGCCTGAG  
10 AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 15).

*A. versicolor* (strain NRRL 238):

CTGAGTGCGGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGACTACCTAACACTGTTGC  
TTCGGCGGGGAGCCCTCTCGGGGGCGAGCCGCCGGGGACTACTGAACTTCATGCCTGAG  
15 AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 16).

*A. versicolor* (strain NRRL 239):

CTGAGTGCGGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGACTACCTAACACTGTTGC  
TTCGGCGGGGAGCCCTCTCGGGGGCGAGCCGCCGGGGACTACTGAACTTCATGCCTGAG  
20 AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 17).

*A. versicolor* (strain CUH3):

CCGAGTGCGGGCTGCCTCCGGGCGCCCAACCTCCCACCCGTGACTACCTAACACTGTTGC  
TTCGGCGGGGAGCCCTCTCGGGGGCGAGCCGCCGGGGACTACTGAACTTCATGCCTGAG  
25 AGTGATGCAGTCTGAGTCTGAATATAAAATCAGTCA (SEQ ID NO: 18).

*A. wentii* (strain 3650):

CCGAGTGAGGACCTAACCGGTCCAACCTCCCACCCGTGTCTATCGTACCTTGTTGCTTCG  
GCGGGCCCGCCATTCTGTGGCCGCCGGGGGGCATCTCGCCCCGGGGCCCGCGCCCGCGG  
30 AGACACCAACACGAACACTGTCTGAAGGTTGCAGTCTGAGTCGATTTATTTAATCGTTA  
(SEQ ID NO: 19).

*A. chevalieri* (strain ATCC 16443):

CCGAGTGCGGGCCCTCTGGGTCCAACCTCCCATCCGTGTCTATCTGTACCCTGTTGCTTC  
GGCGTGGCCACGGCCCCGCCGAGACTAACATTTGAACGCTGTCTGAAGTTTGCAGTCTG  
35 AGTTTTTAGTTAAACAATCGTTA (SEQ ID NO: 20).

*A. chevalieri* (strain ATCC 24546):

CCGAGTGC GGGCCCTCTGGGTCCAACCTCCCATCCGTGTCTATCTGTACCCTGTTGCTTC  
GGCGTGGCCACGGCCCCGCGGAGACTAACATTTGAACGCTGTCTGAAGTTTGCAGTCTG  
AGTTTTTAGTTAAACAATCGTTA (SEQ ID NO: 21).

5

*A. ustus* (strain ATCC 14417):

CCGAGTGCAGGTCTGCCCCCGGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCAAC  
GTTGCTTCGGCGGTGCGCCCCCGGGGGTAGCCGCGGAGACCACACCGAACCTCCTG  
TCTTTAGTGTTGTCTGAGCTTGATAGCAAACCTATTA (SEQ ID NO: 22).

10

*A. ustus* (strain ATCC 16801):

CCGAGTGCAGGTCTGCCCCCGGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCAAC  
GTTGCTTCGGCGGTGCGCCCCCTCCGGGGGTAGCCGCGGAGACCACATTGAACCTCTTGT  
CTTTAGTGTTGTCTGAGCTTGATAGCAAACCTATTA (SEQ ID NO: 23).

15

*A. ustus* (strain NRRL 275):

CCGAGTGCAGGTCTGCCCCCGGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCAAC  
GTTGCTTCGGCGGTGCGCTCCCCCGGGGGCAGCCGCGGAGACCACACCGAACCTCTT  
GTTATAGCGTGTCTGAGCTTGATACAAGCAAACCTAATTA (SEQ ID NO: 24).

20

*A. ustus* (strain NRRL 5077):

CCGAGTGCAGGCCTCGCCCCACAGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCA  
ACGTTGCTTCGGCGGTGCGCGCCCCCTTCCCGGGGGGCGTAAGCCGCCGGGGGACCACAC  
CGAACTTCTTGTTTTTAGCGTGTCTGAGCTTGATACAAGCAAACCTAATTA (SEQ ID

25 NO: 25).

*A. ustus* (strain CUH4):

CCGAGTGCAGGTCTGCCCCCGGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCAAC  
GTTGCTTCGGCGGTGCGCCCCCCCCCGGGGGTAGCCGCGGAGACCACACCGAACCTCCT  
GTCTTTAGTGTTGTCTGAGCTTGATAGCAAACCTATTA (SEQ ID NO: 26).

30

*A. ustus* (strain CUH5):

CCGAGTGCAGGCCTCGCCCCACAGGCAGGCCTAACCTCCCACCCGTGAATACCTGACCA  
ACGTTGCTTCGGCGGTGCGCGCCCCCTTCCCGGGGGGCGTAAGCCGCCGGGGGACCACAC  
CGAACTTCTTGTTTTTAGCGTGTCTGAGCTTGATACAAGCAAACCTAATTA (SEQ ID  
NO: 27).

35

In addition, the disclosure encompasses nucleic acid sequences (which as defined herein also includes the complementary sequence and corresponding RNA sequences) with at least 75% (for example at least 85%, 95% or 98%) sequence identity to the isolated ITS1 sequences from *A. clavatus* (SEQ ID NO: 1), *A. granulosis* (SEQ ID NOs: 2 and 3), and *A. sydowii* (SEQ ID NOs: 4-9). The disclosure also encompasses the isolated ITS1 nucleic acid sequences from *A. flavipes* (SEQ ID NOs: 10-12), *A. restrictus* (SEQ ID NOs: 13 and 14), and *A. versicolor* (SEQ ID NOs: 15-18), or degenerate variants thereof. Such sequences can be used as probes or primers for the detection or amplification of target sequences.

Also disclosed are isolated oligonucleotides (which as defined herein also includes the complementary sequence and corresponding RNA sequences) including at least about 10 consecutive nucleotides, or at least about 15, 20 or 25 consecutive nucleotides, from the *Aspergillus* ITS1 sequences disclosed herein, including any nucleic acid sequences having at least 75% (for example at least 85%, 95% or 98%) sequence identity to the isolated ITS1 sequences from *A. clavatus* (SEQ ID NO: 1), *A. granulosis* (SEQ ID NOs: 2 and 3), and *A. sydowii* (SEQ ID NOs: 4-9). Isolated oligonucleotides can be of at least 10 consecutive nucleotides in length, or 15, 20 or 25 consecutive nucleotides in length, or longer. In one embodiment, the oligonucleotides are from *A. flavipes* (SEQ ID NOs: 10-12), *A. restrictus* (SEQ ID NOs: 13 and 14), and *A. versicolor* (SEQ ID NOs: 15-18), or degenerate variants thereof. These oligonucleotides can be employed as effective DNA hybridization probes or primers useful for amplification. Such probes and primers are particularly useful in the detection and speciation of *Aspergillus*.

In some embodiments, any of the probes or primers disclosed herein is also of a maximum length, for example no more than 15, 25, 40, 50, 75, 100, or 150 nucleotides in length.

Also disclosed herein are the isolated ITS1 nucleic acid sequences from *A. ustus* shown in SEQ ID NOs: 22-27.

Any of the isolated nucleic acid sequences disclosed herein may consist or consist essentially of the disclosed sequences, or comprise nucleic acid molecules that have a maximum length of 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 or 80 contiguous nucleotides of the disclosed sequence. The disclosed contiguous sequences may also be joined at either end to other unrelated sequences.

### III. Method of Detecting *Aspergillus* ITS1 Sequences

The presence of *Aspergillus* within a sample can be detected using the ITS1 sequences described herein. *Aspergillus* DNA can be directly detected or amplified prior to detection and identification of the *Aspergillus* species from which the DNA originated using these ITS1 sequences. In one embodiment, the species of *Aspergillus* in a sample is determined by sequence analysis. The methods described herein can be used for any purpose where the detection of *Aspergillus* is desirable, including diagnostic and prognostic applications, such as in laboratory and clinical settings.

In one embodiment, the detection method includes the step of amplifying with a nucleic acid amplification method an *Aspergillus* ITS1 sequence in a sample of interest. In one specific

embodiment, amplification is by PCR, and the method utilizes two or more oligonucleotide primers from the ITS1 sequences, followed by sequence analysis for identification of the *Aspergillus* species. In one specific, non-limiting example, PCR is utilized for amplification.

Appropriate samples include any conventional environmental or biological samples, including clinical samples obtained from a human or veterinary subject, for instance blood or blood-fractions (e.g., serum), sputum, saliva, oral or washings, skin scrapes, biopsied tissue (for example bronchoscopy samples), bronchoalveolar lavage (BAL) washings, cerebrospinal fluid, or prostate fluid. Standard techniques for acquisition of such samples are available (see, e.g. Schluger *et al.*, *J. Exp. Med.* 176:1327-33, 1992; Bigby *et al.*, *Am. Rev. Respir. Dis.* 133:515-18, 1986; Kovacs *et al.*, *NEJM* 318:589-93, 1988; and Ognibene *et al.*, *Am. Rev. Respir. Dis.* 129:929-32, 1984). The sample can be used directly or can be processed, such as by adding solvents, preservatives, buffers, or other compounds or substances.

In one embodiment, nucleic acids are isolated from the sample. DNA or RNA can be extracted using standard methods. For instance, rapid DNA preparation can be performed using a commercially available kit (e.g., the Qiagen Tissue Kit, Qiagen, Inc., Valencia, CA). The DNA preparation technique can be chosen to yield a nucleotide preparation that is accessible to and amenable to nucleic acid amplification.

In one specific, non-limiting example, universal fungal primers ITS5 (SEQ ID NO: 28), ITS2 (SEQ ID NO: 29), and ITS4 (SEQ ID NO: 30) (see Figure 1) are used to amplify the identified sequences from *A. clavatus* (SEQ ID NO: 1), *A. granulosis* (SEQ ID NOs: 2 and 3), and *A. sydowii* (SEQ ID NOs: 4-9), or sequences 75%, 85%, 90%, or 95% identical, followed by sequence analysis to determine the presence of the *Aspergillus* species. In another specific, non-limiting example, the same universal primers are used to amplify the identified sequences from *A. flavipes* (SEQ ID NOs: 10-12), *A. restrictus* (SEQ ID NOs: 13 and 14), *A. versicolor* (SEQ ID NOs: 15-18), *A. wentii* (SEQ ID NO: 19), and *A. chevalieri* (SEQ ID NOs: 20 and 21), or degenerate variants thereof, followed by sequence analysis to determine the presence of the *Aspergillus* species.

In an additional specific, non-limiting example, the *Aspergillus* ITS1 region is amplified using oligonucleotide primers of at least 15 consecutive nucleotides of the isolated ITS1 sequences from *A. clavatus* (SEQ ID NO: 1), *A. granulosis* (SEQ ID NOs: 2 and 3), *A. sydowii* (SEQ ID NOs: 4-9), *A. flavipes* (SEQ ID NOs: 10-12), *A. restrictus* (SEQ ID NOs: 13 and 14), *A. versicolor* (SEQ ID NOs: 15-18), *A. wentii* (SEQ ID NO: 19), and *A. chevalieri* (SEQ ID NOs: 20 and 21), followed by sequence differentiation (for example sequence analysis) to determine the presence of the *Aspergillus* species. Sequence analysis can include, for example, obtaining the sequence of the amplified ITS1 region, or using a probe to identify specific identifying sequences within the amplified ITS1 region. In particular embodiments, the probe or primer comprises at least 15 contiguous nucleotides, such as at least 18 contiguous nucleotides, for example 15-18 contiguous nucleotides, of the following sequences:

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A. granulosus

CAGGTCTGCCCCTGGCAG (SEQ ID NO: 33)  
 50)  
 GTCTGCCCCTGGCAGGCC (SEQ ID NO: 34)  
 5 51)  
 TGCCCCTGGCAGGCCTAA (SEQ ID NO: 35)  
 52)  
 ACCGAACCTTCTTGTTA (SEQ ID NO: 36)  
 53)  
 10 GAACCTTCTTGTTAAGC (SEQ ID NO: 37)  
 54)  
 CCTTCTTGTTAAGCCTG (SEQ ID NO: 38)  
 55)  
 TCTTGTTAAGCCTGTTG (SEQ ID NO: 39)  
 15 56)  
 TGTTAAGCCTGTTGTCT (SEQ ID NO: 40)  
 57)  
 TTAAGCCTGTTGTCTGAG (SEQ ID NO: 41)  
 58)  
 20 AGCCTGTTGTCTGAGCTT (SEQ ID NO: 42)  
 59)  
 CTGTTGTCTGAGCTTGAT (SEQ ID NO: 43)  
 60)  
 TTGTCTGAGCTTGATAGC (SEQ ID NO: 44)  
 25 TCTGAGCTTGATAGCAAA (SEQ ID NO: 45)  
 GAGCTTGATAGCAAATCT (SEQ ID NO: 46)  
 CTTGATAGCAAATCTATTA (SEQ ID NO: 47)  
 TTGTTAAGCCTGTTGTC (SEQ ID NO: 48)  
 TTTAAGCCTGTTGTCTGA (SEQ ID NO: 49)  
 30 64)  
 65)  
 66)  
 35 67)

A. nidulans

TTTCATGCCTGAGAGTGA (SEQ ID NO:  
 CATGCCTGAGAGTGATGC (SEQ ID NO:  
 GCCTGAGAGTGATGCAGT (SEQ ID NO:  
 TGAGAGTGATGCAGTCTG (SEQ ID NO:  
 GAGTGATGCAGTCTGAGC (SEQ ID NO:  
 TGATGCAGTCTGAGCCTG (SEQ ID NO:  
 TGCAGTCTGAGCCTGAAT (SEQ ID NO:  
 AGTCTGAGCCTGAATACA (SEQ ID NO:  
 CTGAGCCTGAATACAAAT (SEQ ID NO:  
 AGCCTGAATACAAATCAG (SEQ ID NO:  
 CTGAATACAAATCAGTCA (SEQ ID NO:

A. ustus

CTGTCTTTAGTGTTGTCT (SEQ ID NO: 61)  
 TCTTTAGTGTTGTCTGAG (SEQ ID NO: 62)  
 TTAGTGTTGTCTGAGCTT (SEQ ID NO: 63)  
 GTGTTGTCTGAGCTTGAT (SEQ ID NO:  
 TTGTCTGAGCTTGATAGC (SEQ ID NO:  
 GAGCTTGATAGCAAACCT (SEQ ID NO:  
 CTTGATAGCAAACCTATTA (SEQ ID NO:

In a further specific, non-limiting example, the *Aspergillus* ITS1 region is amplified using universal fungal primers ITS5 (SEQ ID NO: 28), ITS1 (SEQ ID NO: 31), ITS2 (SEQ ID NO: 29), and ITS4 (SEQ ID NO: 30), followed by hybridization with oligonucleotide probes comprising at least 15 consecutive nucleotides (for example 15-18 nucleotides) of an ITS1 region of SEQ ID NO: 1, SEQ ID NOs: 2 or 3, SEQ ID NOs: 4, 5, 6, 7, 8 or 9, SEQ ID NOs: 10, 11 or 12, SEQ ID NOs: 13 or 14, SEQ ID NOs: 15, 16, 17 or 18, SEQ ID NO: 19, or SEQ ID NOs: 20 and 21 to determine the presence of the *Aspergillus* species. In particular embodiments, the probe comprises at least 15 contiguous nucleotides, such as at least 18 contiguous nucleotides, of the above listed probe sequences.

#### IV. Kits

The oligonucleotide primers disclosed herein can be supplied in the form of a kit for use in detection of *Aspergillus*. In such a kit, one or more of the oligonucleotide primers is provided in one or more containers. An oligonucleotide primer can be provided suspended in an aqueous solution, or as a freeze-dried or lyophilized powder. The container(s) in which the oligonucleotide(s) are supplied can be any conventional container that is capable of holding the supplied form; e.g., microfuge tubes, ampoules, or bottles. In some applications, pairs of primers can be provided in pre-measured single use amounts in individual, typically disposable, tubes or equivalent containers. With such an arrangement, the sample to be tested for the presence of *Aspergillus* nucleic acids can be added to the individual tubes and amplification carried out directly, followed by sequence analysis.

In some embodiments, kits can also include the reagents necessary to carry out PCR amplification reactions, including DNA sample preparation reagents, appropriate buffers (e.g., polymerase buffer), salts (e.g., magnesium chloride), and deoxyribonucleotides (dNTPs). One or more control sequences for use in the PCR reactions can also be supplied in the kit.

In one embodiment, kits are supplied with instructions. In one specific, non-limiting example, the instructions are written instructions. In another such example, the instructions are contained in a videocassette or in a CD. The instructions may, for example, instruct the user how to use the primers to amplify the nucleic acid sequences, and then differentiate the species (and/or strains) of *Aspergillus* using the ITS1 sequences disclosed herein. In one specific non-limiting example, the instructions direct the user to sequence the amplified nucleic acid to detect sequence differences indicative of the different *Aspergillus*. Alternatively, probes may be used to detect the different sequences that are associated with each species or strain.

#### EXAMPLES

The following examples are provided to illustrate particular features of certain embodiments, but the scope of the claims should not be limited to those features exemplified.

**Example 1****Materials and Methods***Isolation of Fungal DNA*

*Aspergillus* isolates were grown on Czapek-Dox agar (Difco Laboratories, Detroit, MI) for 10 to 14 days at 25 °C and at 37 °C to confirm their purity, to identify species based on morphological and other traditional characteristics, and to generate fungal growth for DNA extraction.

Fungal biomass, scraped from the surface of one agar plate, was transferred into a pre-cooled (-20 °C) sterile ceramic mortar, overlaid with liquid nitrogen, and slowly ground with a pestle into a fine powder. The powder was suspended in 2 ml of G-2 buffer (Genomic DNA buffer set, Qiagen, Inc.) containing RNase (Sigma Chemical Co., St. Louis, MO), and transferred into an Oak Ridge centrifugation tube (Nalge Nunc International, Rochester, NY). Following the addition of 45 µl of proteinase K solution (Roche Molecular Biochemicals, Indianapolis, IN), the suspension was incubated with intermittent agitation at 55 °C for 2 hours. The crude extract was centrifuged at 22,870 x g for 10 minutes and the supernatant was transferred to a Falcon tube (Becton Dickinson, Franklin Lakes, NJ), and briefly vortex-mixed. DNA was then purified using Genomic-tip 20/G columns (Qiagen, Inc.) according to the manufacture's instructions. The eluted DNA was supplemented with 2.5 µl of glycogen solution (Gentra Systems, Minneapolis, MN), precipitated by standard methods (see Sambrook *et al.*), and resuspended in 60 µl of DNA rehydration buffer (PureGene kit, Gentra Systems).

*Extraction of Aspergillus DNA from Biological Samples*

1 ml of a biological sample was incubated with 1 ml of lysis solution (1 N NaOH, 0.2 M sodium citrate, 0.4 M N-acetylcysteine) on a shaker at room temperature for 30 minutes. The sample was then centrifuged at 12,000 rpm for 10 minutes in a microfuge. The supernatant was removed, 2 ml of lysis solution was added, and the pellet was resuspended by vortexing for 30 seconds. The sample was again centrifuged at 12,000 rpm for 10 minutes in a microfuge. The supernatant was removed and the pellet was resuspended in 2 ml of 20 mM Tris-HCl (pH 8.3), followed by centrifugation at 12,000 rpm for 10 minutes in a microfuge. The supernatant was removed, 300 µl of sorbitol buffer (1 M sorbitol, 100 mM EDTA), 10 µl of β-mercaptoethanol, and 200 units of zymolyase were added, and the pellet was resuspended by briefly vortexing several times. The mixture was incubated at 35 °C for 1.5 hours on a shaker, followed by centrifugation at 6,000 rpm for 15 minutes in a microfuge. The supernatant was removed and the pellet resuspended in 2 ml of sorbitol buffer. The sample was again centrifuged at 6,000 rpm for 15 minutes in a microfuge. The supernatant was removed and the pellet was resuspended in 180 µl of ATL lysis buffer (Qiagen, Inc.). Following the addition of 20 µl of a proteinase K solution (Qiagen, Inc.), the sample was incubated at 55 °C for 1.5 hours on a shaker. The sample was then centrifuged at 8,000 rpm for 20 minutes in a microfuge. The supernatant was removed and the pellet was resuspended in 200 µl of 20 mM Tris-

HCl (pH 8.3), followed by boiling in a water bath for 40 minutes. DNA was then purified using QIAamp DNA columns (Qiagen, Inc.) according to the manufacture's instructions.

#### *Preparation of Primers and Probes*

5 All primers and probes were synthesized by  $\beta$ -cyanoethyl phosphoramidite chemistry using a 394 or expedite automated DNA synthesizer (PE Applied Biosystems, Foster City, CA).

ITS3, a universal fungal sequence located in the 5.8S region of the fungal rDNA and contained within the region amplified by the ITS5 and ITS2 or ITS5 and ITS4 primers, was biotinylated at the 5' end by incorporating dimethoxytrityl-biotin-carbon-6-phosphoramidite during  
10 its synthesis. This biotinylated probe (ITS3-B) was then purified by reverse phase liquid chromatography.

Digoxigenin-labeled probes were synthesized with a 5'-terminal amine group using 5' Amino-Modifier C6 (Glen Research, Sterling, VA), mixed with a 10-fold molar excess of digoxigenin-3-O-methylcarbonyl- $\epsilon$ -aminocaproic acid N-hydroxysuccinimide ester (Roche) in 0.1 M  
15 sodium carbonate buffer, pH 9.0, and incubated at ambient temperature overnight. The digoxigenin-labeled probes were then purified by reverse-phase high-pressure liquid chromatography, Becker, *et al.*, *J. Chromatogr.* 326:293-299, 1985.

#### *PCR Amplification of rDNA Internal Transcribed Spacer 1*

20 The PCR reaction mix consisted of 10 mM Tris-HCl buffer containing 50 mM KCl, pH 8.0 (Roche), 1.5 mM MgCl<sub>2</sub> (Roche), 0.2 mM dNTPs (Roche) and 1.25 U Taq polymerase (Roche). Primers ITS5 and ITS2, or ITS5 and ITS4, were added to a final concentration of 20 pM each. Template DNA was added at a final concentration of 1 ng per 50  $\mu$ l reaction mix. For each experiment, at least one reaction tube received water in place of template DNA as a negative control.  
25 Amplification was performed in a GeneAmp PCR System 9700 (PE Applied Biosystems). Initial denaturation of template DNA was achieved by heating at 95 °C for 5 minutes. This was followed by 30 cycles of 95 °C for 30 seconds, 58 °C for 30 seconds, and 72 °C for 1 minute. A final extension step was conducted for 5 minutes at 72 °C. Appropriate controls were included and PCR contamination precautions were followed, Fujita *et al.*, *J. Clin. Microbiol.* 33:962-67, 1995.

#### *Sequence Analysis*

30 PCR products generated with either primer pairs ITS5 and ITS2, ITS5 and ITS4, ITS1 and ITS2, or ITS1 and ITS4, were purified using the QIAquick PCR purification kit (Qiagen, Inc.) according to the manufacture's protocol. Purified products were sequenced on both strands using the same primers as initially used for PCR amplification, and the BigDye Termination Cycle Sequencing Ready Reaction Kit (PE Applied Biosystems) as recommended by the manufacturer. Cycle sequencing on a GeneAmp PCR System 9700 consisted of an initial denaturation at 96 °C for 5 minutes, followed by 30 cycles of 96 °C for 10 seconds, 50 °C for 5 seconds, and 60 °C for 4 minutes. Sequencing products were purified using the Dye-Ex Spin Kit (Qiagen, Inc.), dried in a

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vacuum centrifuge, and resuspended in formamide. Sequencing products were analyzed on an automated capillary DNA sequencer (ABI Prism 310 Genetic Analyzer, PE Applied Biosystems) according to the manufacturer's instructions. GenBank searches and comparative sequence analysis were assisted by the BLAST search tools, the Genetics Computer Group software package (University of Wisconsin, Madison), and the Clustal W alignment program (Thompson *et al.*, *Nucleic Acids Research* 22:4673-80, 1994).

### Example 2

#### Comparative Analysis of *Aspergillus* ITS1 Consensus Sequences

A total of 46 ITS1 consensus sequences ranging in length from 142 nucleotides (*A. chevalieri*) to 187 nucleotides (*A. clavatus*) were compiled (Table I). Overall, 5 regions with significant interspecies variability in length and sequence were recognized (Figure 2). These hypervariable regions were defined as follows: ITS1-V1, position 8-30 (12-21 nucleotides in length); ITS1-V2, position 50-67 (13-14 nucleotides in length); ITS1-V3, position 81-141 (12-54 nucleotides in length); ITS1-V4, position 151-181 (23-28 nucleotides in length); and ITS1-V5, position 192-215 (17-21 nucleotides in length). Compared to the ITS1-V3 sequence of *A. niger* (54 nucleotides), notably shorter corresponding sequences were found for *A. chevalieri* (12 nucleotides), *A. granulosis* (21 nucleotides), *A. ustus* (21-30 nucleotides), *A. sydowii* (22 nucleotides), *A. versicolor* (22 nucleotides), and *A. nidulans* (21-22 nucleotides). In general, intraspecies diversity was  $\leq 5$  nucleotides and mainly present in the ITS1-V3 region, except for the very diverse *A. ustus* sequences. They differed from one another at a total of 33 positions within the ITS1-V1, -V3, -V4, and -V5 regions, thereby revealing two main types of *A. ustus* ITS1 sequences with characteristic nucleotides at positions 185, 202-204 and 215.

ITS1 sequence diversity enabled discrimination between *Aspergillus* species disclosed herein as estimated from comparisons between *A. nidulans* and closely related species (Table II). Sequence similarities of  $\leq 77.3\%$ ,  $\leq 80.5\%$ ,  $\leq 95.4\%$ , and  $\leq 96.7\%$  were determined for *A. nidulans* in comparison to *A. granulosis*, *A. ustus*, *A. sydowii*, and *A. versicolor*, respectively. *A. granulosis* compared to *A. ustus* exhibited moderate similarity ( $\leq 94.2\%$ ) whereas a high value of  $\leq 98.1\%$  resulted for *A. sydowii* compared to *A. versicolor*. Using the same algorithm, intraspecies similarities of 99.3%, 100%,  $\geq 89.0\%$ , 98.7%, and 99.4% were found for the strains representing *A. nidulans*, *A. granulosis*, *A. ustus*, *A. sydowii*, and *A. versicolor*, respectively. The broad range of intraspecies similarities for *A. ustus* ( $\geq 89.0\%$ -99.4%) clearly reflected the presence of very diverse ITS1 sequences among the strains investigated as described above.

Species differentiation can be particularly efficiently performed by comparing or detecting sequence differences in the five hypervariable regions of ITS1. These hypervariable regions correspond to residues 8 to 31, 50 to 67, 81 to 141, 151 to 181, and 192 to 215 of the ITS1 alignment sequence shown in Figure 2, where dots symbolize identical nucleotides compared to the *A. niger* I sequence, and dashes indicate alignment gaps. For example, the first hypervariable region of the *A.*

- niger* I sequence comprises the sequence C-GGG-----TCCTTTGG-----G; the second hypervariable region comprises the sequence TCTA--TTGT-ACCC--T; the third hypervariable region comprises the sequence -GCCCCGCCGCTTGTC-----GGCCGCCGGGGGGGCGCCTCT--GCCCCCGGGCCCGTGCCC; the fourth hypervariable region comprises the sequence CCCAACAC--GAACACTGT--CTGAAAGCG; and the fifth
- 5 hypervariable region comprises the sequence GTT--GATTGAAT-GCAA-TCA-G.

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**TABLE I**  
**Source and characterization of *Aspergillus* strains disclosed herein.**

Species	Strain <sup>a</sup>	ITS1	
		GenBank accession no.	Length (nt) <sup>b</sup>
<i>A. candidus</i>	NRRL 303	AF453881	180
	NRRL 312	AF453882	180
<i>A. chevalieri</i>	ATCC 16443	AF453883	142
	ATCC 24546	AF453884	142
<i>A. clavatus</i>	ATCC 9192		187
<i>A. flavipes</i>	ATCC 11013	AF453886	185
	ATCC 16805	AF453887	184
	ATCC 24487	AF453888	185
<i>A. flavus</i>	ATCC 11497	AF453890	181
	ATCC 34896	AF453891	181
	ATCC 44310	AF453892	181
	ATCC 64025	AF453893	181
<i>A. fumigatus</i>	ATCC 16903	AF453895	184
	CDC 2570	AF453896	184
<i>A. granulosis</i>	CBS 119.5A	AF453897	156
	NRRL 1932	AF453898	156
<i>A. nidulans</i>	ATCC 16855	AF453899	153
	ATCC 64027	AF453900	153
	CDC 040487	AF453924	154
<i>A. niger</i>	ATCC 1015	AF453901	185
	ATCC 16404	AF453902	185
	ATCC 64028	AF453903	185
<i>A. parasiticus</i>	ATCC 56775	AF453906	179
<i>A. restrictus</i>	NRRL 148	AF453907	181
	NRRL 151	AF453908	181
<i>A. sydowii</i>	NRRL 250	AF453909	155
	NRRL 4768	AF453910	155

	CUH1 <sup>c</sup>	AF453911	155
	CUH2 <sup>c</sup>	AF453912	155
	CUH7 <sup>c</sup>	AF453913	155
	CUH8 <sup>c</sup>	AF453914	155
<i>A. tamarit</i> <sup>d</sup>	ATCC 64841	AF453894	182
<i>A. terreus</i>	ATCC 1012	AF453915	186
	ATCC 10029	AF453916	186
	ATCC 7860	AF453917	186
<i>A. ustus</i>	ATCC 14417	AF453918	155
	ATCC 16801	AF453919	155
	NRRL 275	AF453920	161
	NRRL 5077	AF453921	172
	CUH4 <sup>c</sup>	AF453922	156
	CUH5 <sup>c</sup>	AF453923	172
<i>A. versicolor</i>	ATCC 10072	AF453925	155
	NRRL 238	AF453926	155
	NRRL 239	AF453927	155
	CUH3 <sup>c</sup>	AF453928	155
<i>A. wentii</i>	NRRL 3650		178

<sup>a</sup> ATCC, American Type Culture Collection, Manassas, Virg.; CBS, Centraalbureau voor Schimmelfcultures, Utrecht, The Netherlands; CDC, Centers for Disease Control and Prevention, Atlanta, Ga.; NRRL, Agricultural Research Service (ARS) Culture Collection, Peoria, Ill.

<sup>b</sup> Number of nucleotides determined by sequence analysis.

5 <sup>c</sup> Clinical isolate, kindly provided by Dr. J. H. Shin, Department of Clinical Pathology, Chonnam University Medical School, Kwangju, South Korea.

<sup>d</sup> Deposited in ATCC as *A. flavus*.

TABLE II  
ITS1 sequence similarities for *A. nidulans* and closely related species

Organism <sup>a</sup>		% Similarity with species/sequenar <sup>b</sup>												
Species	ITS1- Sequencar	AG	AU			V			AS		AV		AN	
			I	II	III	IV	V	I	II	I	II	I	II	
<i>A. granulatus</i> (AG)														
		100												
<i>A. ustus</i> (AU)	I	93.5	100											
	II	93.5	97.4	100										
	III	93.5	99.4	97.4	100									
	IV	94.2	94.2	92.9	93.6	100								
	V	88.5	90.3	89.0	89.7	92.5	100							
<i>A. sydowii</i> (AS)	I	73.3	73.5	70.0	72.4	69.5	62.6	100						
	II	73.3	73.5	77.9	72.4	70.8	63.2	98.7	100					
<i>A. versicolor</i> (AV)	I	72.7	72.8	77.2	71.7	68.8	61.9	98.1	98.1	100				
	II	73.3	73.5	77.9	72.4	69.5	62.6	97.4	97.4	99.4	100			
<i>A. nidulans</i> (AN)	I	75.3	75.5	79.2	75.5	71.7	63.4	95.4	95.4	96.1	96.7	100		
	II	77.3	76.8	80.5	75.7	71.2	64.3	94.8	94.8	95.5	96.1	99.3	100	

<sup>a</sup> Strains as listed in legend to Figure 2.

<sup>b</sup> Similarities have been determined with complete ITS1 sequences as shown in Figure 2 using the GAP algorithm (GCG).

## Example 3

## Polymerase Chain Reaction-Enzyme Immunoassay (EIA)

Enzyme immunoassay (EIA) identification of PCR products is performed as described in Elie *et al.*, *J. Clin. Microbiol.* 36:3260-65, 1998 and Fujita *et al.*, *J. Clin. Microbiol.* 33:962-67, 1995, with minor  
 5 modifications.

Briefly, tubes containing 10  $\mu$ l of heat-denatured (5 min at 95  $^{\circ}$ C) PCR products are placed on ice, and 200  $\mu$ l of hybridization buffer (4X SSC, pH 7.0, 0.02M HEPES, 0.002M EDTA, 0.15% Tween 20) containing 10 ng of ITS3-B and 10 ng of a digoxigenin-labeled specific probe is added. Samples are mixed and incubated at 37  $^{\circ}$ C for 1 hour. 100  $\mu$ l of the mixture is added in duplicate to each well of a streptavidin-  
 10 coated (Roche), 96-well, microtiter plate and incubated at ambient temperature for 1 hour on a microtiter plate shaker (Labline Instruments, Melrose Park, IL) at ~350 rpm. Microtiter plates are washed 6 times with 0.01 M phosphate buffered saline, pH 7.2, containing 0.05% Tween 20 (PBST) before adding 100  $\mu$ l of a 1:1000 dilution of horseradish peroxidase-labeled, anti-digoxigenin antibody (150 U/ml, Roche) per  
 15 well. Plates are incubated for 1 hour at ambient temperature with shaking and then washed 6 times with PBST. 3,3',5,5'-Tetramethylbenzidine (TMB)-H<sub>2</sub>O<sub>2</sub> substrate (Kirkegaard and Perry, Gaithersburg, MD) is then added to the wells and the color reaction is allowed to develop at ambient temperature for 15 minutes. The optical density of each well is immediately read at a wavelength of 650 nm in a UVMax microtiter plate reader (Molecular Devices, Sunnyvale, CA). The optical density of the duplicate wells are averaged and converted to an EIA index (EI) which is calculated by dividing the optical density value of the wells  
 20 which have received test DNA by the optical density of the PCR water control. An example of EIA identification of PCR products is shown in Table III.

Student's *t* test is used to determine differences between the mean EI of probe hybridization to homologous and heterologous DNA. Differences are considered significant when the value of *P* is less than or equal to 0.05.

TABLE III

Species specificities of DNA probes analyzed by hybridization with PCR products in an EIA

Genomic DNA tested	EIA detection of PCR products with probe				
	AG	AU	AS	AV	AN
30 <i>A. granulosis</i> (AG)	++	--	--	--	--
<i>A. ustus</i> (AU)	--	++	--	--	--
<i>A. sydowii</i> (AS)	--	--	++	--	--
<i>A. versicolor</i> (AV)	--	--	--	++	--
35 <i>A. nidulans</i> (AN)	--	--	--	--	++

#### Example 4

##### DNA Sequence Based Identification of *Aspergillus* species

This example illustrates how DNA based sequence identification can be used to identify different species of *Aspergillus*. A biological sample is obtained from an infected subject, and the fungus is cultured under conditions suitable for the growth of *Aspergillus*, followed by isolation of fungal DNA as described in Example 1, *Isolation of Fungal DNA*. Alternatively, the fungal DNA can be extracted directly from the biological sample as described in Example 1, *Extraction of Aspergillus DNA from Biological Samples*. The universal primer pairs ITS5 and ITS2, ITS5 and ITS4, ITS1 and ITS2, or ITS1 and ITS4 are added to the reaction mixture, as in Example 1, to amplify the fungal DNA present in the mixture, followed by sequence analysis as described in Example 1.

In one embodiment, following general amplification of the fungal DNA present in the sample using the universal primer pairs, specific primers from the hypervariable regions of ITS1 are used to amplify DNA from this region, and that DNA is subjected to DNA sequence analysis. In particular embodiments, the primer comprises at least 15 contiguous nucleotides, such as at least 18 contiguous nucleotides, of the primer sequences shown above (III. *Method of Detecting Aspergillus ITS1 Sequences*). This sequence information is compared to the fungal DNA sequences disclosed herein (SEQ ID NOs: 1-27), and a sequence match will confirm the identity of the *Aspergillus* species.

In yet another embodiment, general amplification of the fungal DNA present in the sample using the universal primer pairs is omitted, and specific primers from the hypervariable regions of ITS1 are used to amplify DNA from this region, and that DNA is subjected to DNA sequence analysis. In particular embodiments, the primer comprises at least 15 contiguous nucleotides, such as at least 18 contiguous nucleotides, of the primer sequences shown above (III. *Method of Detecting Aspergillus ITS1 Sequences*). This sequence information is compared to the fungal DNA sequences disclosed herein (SEQ ID NOs: 1-27), and a sequence match will confirm the identity of the *Aspergillus* species.

This technique has utility in rapidly and reliably identifying a single species of *Aspergillus* on a culture plate, in clinical specimens, in food, pharmaceuticals, and in environmental or other samples.

#### Example 5

##### Base Pair Differences Between Given Species by ITS or D1/D2 Region

The information in this Example illustrates that the inventors have found that there is substantial diversity between *Aspergillus* species in the ITS1 region, compared to the ITS2 region. This greater diversity allows the DNA sequence information to provide a better identification of the species. For example, there are approximately 48 base pair differences between *A. ustus* and *A. nidulans* in the ITS1 region, whereas there are only 6 base pair differences between these species in the ITS2 region.

The following Table IV illustrates the surprisingly superior ability of the ITS1 region to be informative about the identification of the *Aspergillus* species.

**TABLE IV**  
**Base Pair Differences Between Given Species by ITS or D1/D2 Region**

Base pair differences between given species by ITS or D1/D2 region:			
Species	ITS1	ITS2	D1/D2
ustus vs. nidulans	48	6	3
sydowii vs. nidulans	9	9	7
granulosus vs. nidulans	52	10	4
granulosus vs. ustus	6	5	1
sydowii vs. versicolor	3	4	2
versicolor vs. nidulans	7	10	9
sydowii vs. ustus	40	7	9
sydowii vs. candidus	93	24	20
niger vs. versicolor	90	29	15
niger vs. sydowii	93	26	15

5

The foregoing examples are provided by way of illustration only. One of skill in the art will appreciate that numerous variations on the nucleotide sequences and methods described herein can be employed to make and use oligonucleotide primers for the amplification of *Aspergillus* ITS1 sequences, and for their use in the detection and species identification of *Aspergillus*. We claim all such modifications and variations that fall within the scope and spirit of the claims below.

10

## CLAIMS

We claim:

1. A method of distinguishing species of *Aspergillus* from one another, comprising  
5 detecting differences in two or more of ITS1-V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 nucleic acid sequences of *Aspergillus*.
2. The method of claim 1, wherein detecting differences comprises detecting differences in  
10 three or more of the ITS1-V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 nucleic acid sequences.
3. The method of claim 2, wherein detecting differences comprises detecting differences in  
all of the ITS1-V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 nucleic acid sequences.
4. The method of claim 1, wherein detecting differences comprises sequencing the two or  
15 more nucleic acid sequences.
5. The method of claim 4, wherein sequencing comprises amplifying the sequences before  
sequencing the nucleic acid sequences.
- 20 6. The method of claim 1, wherein the method comprises distinguishing among *Aspergillus*  
*granulosus*, *ustus*, *sydowii*, *versicolor* and *nidulans*.
7. The method of claim 6, wherein the method further comprises distinguishing among  
*Aspergillus clavatus*, *flavipes*, *restrictus*, *wentii*, and *chevalieri*.
- 25 8. The method of claim 1, wherein distinguishing species comprises identifying the ITS1-  
V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 sequences of
  - (a) SEQ ID NO: 1 or a degenerate variant thereof to identify *Aspergillus clavatus*;
  - (b) SEQ ID NO: 2, SEQ ID NO: 3 or a degenerate variant thereof to identify *Aspergillus*  
30 *granulosus*;
  - (c) SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, SEQ  
ID NO: 9 or a degenerate variant thereof to identify *Aspergillus sydowii*.
9. The method of claim 1, wherein distinguishing species of *Aspergillus* comprises  
35 amplifying the *Aspergillus* species internal transcribed spacer 1 region and determining a sequence of the  
amplified region.

10. The method of claim 1, wherein distinguishing species of *Aspergillus* further comprises distinguishing among strains of the species.

5 11. The method of claim 10, wherein distinguishing among strains of the species comprises distinguishing between *Aspergillus granulatus* CBS 119.5A and NRRL 250, *Aspergillus sydowi* iNRRL, CUH1, CUH2, CUH7 and CUH8.

12. The method of claim 1, wherein distinguishing species comprises identifying the ITS1-  
10 V1, ITS-V2, ITS-V3, ITS-V4, and ITS-V5 nucleotide sequences of

(a) SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12 or a degenerate variant thereof to identify *A. flavipes*;

(b) SEQ ID NO: 13, SEQ ID NO: 14 or a degenerate variant thereof to identify *A. restrictus*

15 (c) SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, SEQ ID NO: 18 or a degenerate variant thereof to identify *A. versicolor*;

(d) SEQ ID NO: 19 or a degenerate variant thereof to identify *A. wentii*.

(e) SEQ ID NO: 20, SEQ ID NO: 21 or a degenerate variant thereof to identify *A. chevalieri*.

20

13. The method of claim 8, wherein (a) comprises a nucleotide sequence with at least 75% sequence identity to SEQ ID NO: 1, (b) comprises a nucleotide sequence with at least 75% sequence identity to SEQ ID NO: 2 or SEQ ID NO: 3, and (c) comprises a nucleotide sequence with at least 75% sequence identity to SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, or  
25 SEQ ID NO: 9

14. The method of claim 8, wherein (a) comprises a nucleotide sequence with at least 85% sequence identity to SEQ ID NO: 1, (b) comprises a nucleotide sequence with at least 85% sequence identity to SEQ ID NO: 2 or SEQ ID NO: 3, and (c) comprises a nucleotide sequence with at least 85%  
30 sequence identity to SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, or SEQ ID NO: 9.

15. The method of claim 8, wherein (a) comprises a nucleotide sequence with at least 95% sequence identity to SEQ ID NO: 1, (b) comprises a nucleotide sequence with at least 95% sequence  
35 identity to SEQ ID NO: 2 or SEQ ID NO: 3, and (c) comprises a nucleotide sequence with at least 95%

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sequence identity to SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, or SEQ ID NO: 9.

- 5
16. The method of claim 8, wherein (a) comprises SEQ ID NO: 1.
17. The method of claim 8, wherein (b) comprises SEQ ID NO: 2 or SEQ ID NO: 3.
18. The method of claim 8, wherein (c) comprises SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8 or SEQ ID NO: 9.
- 10
19. The method of claim 12, wherein (a) comprises SEQ ID NO: 10, 11 or 12.
20. The method of claim 12, wherein (b) comprises SEQ ID NO: 13 or 14.
- 15
21. The method of claim 12, wherein (c) comprises SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, or SEQ ID NO: 18.
22. The method of claim 12, wherein (d) comprises SEQ ID NO: 19.
- 20
23. The method of claim 12, wherein (e) comprises SEQ ID NO: 20 or SEQ ID NO: 21.
24. The method of claim 5, wherein the amplifying comprises amplifying by polymerase chain reaction (PCR).
- 25
25. The method of claim 1, wherein detecting differences comprises detecting differences in the nucleic acid sequences with nucleic acid probes..
26. A method of detecting the presence of an *Aspergillus* species in a biological sample, comprising:
- 30
- amplifying an *Aspergillus* species internal transcribed spacer 1 region using oligonucleotide primers comprising at least 15 consecutive nucleotides of one or more of (a), (b), (c), (d), (e), (f), (g) or (h):
- 35
- (a) SEQ ID NO: 1;
- (b) SEQ ID NO: 2 or 3;
- (c) SEQ ID NO: 4, 5, 6, 7, 8 or 9;
- (d) SEQ ID NO: 10, 11 or 12;

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- (e) SEQ ID NO: 13 or 14;
- (f) SEQ ID NO: 15, 16, 17, or 18;
- (g) SEQ ID NO: 19;
- (h) SEQ ID NO: 20 or 21,

- 5 and sequencing the internal transcribed spacer 1 region, wherein wherein the nucleic acid sequence of (a) identifies an *Aspergillus clavatus*, (b) identifies an *Aspergillus granulosis*, (c) identifies an *Aspergillus sydowii*, (d) identifies an *Aspergillus flavipes*, (e) identifies an *Aspergillus restrictus*, (f) identifies an *Aspergillus versicolor*, (g) identifies an *Aspergillus wentii*, and (h) identifies an *Aspergillus chevalieri*.
- 10 27. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NO: 1, and the method identifies an *Aspergillus clavatus*.
28. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NO: 2 or 3, and the method identifies an *Aspergillus granulosis*.
- 15 29. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NO: 4, 5, 6, 7, 8 or 9, and the method identifies an *Aspergillus sydowii*.
- 20 30. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NO: 10, 11 or 12 and the method identifies an *Aspergillus flavipes*.
31. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NO: 13 or 14, and the method identifies an *Aspergillus restrictus*.
- 25 32. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NO: 15, 16, 17 or 18, and the method identifies an *Aspergillus versicolor*.
33. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NO: 19, and the method identifies an *Aspergillus wentii*.
- 30 34. The method of claim 26, wherein the oligonucleotide primer comprises at least 15 consecutive nucleotides of SEQ ID NOs: 20 and 21, and the method identifies an *Aspergillus chevalieri*.
- 35 35. The method of claim 26, wherein detecting the presence of an *Aspergillus* species further comprises detecting the presence of a strain of the species, wherein

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(a) SEQ ID NO: 2 identifies strain *Aspergillus granulosis* CBS 119.5A, and SEQ ID NO: 3 identifies *Aspergillus granulosis* strain NRRL 1932;

(b) SEQ ID NO: 4 identifies *Aspergillus sydowii* strain NRRL 250, SEQ ID NO: 5 identifies *Aspergillus sydowii* strain NRRL 4768, SEQ ID NO: 6 identifies *Aspergillus sydowii* strain CUH1, SEQ ID NO: 7 identifies *Aspergillus sydowii* strain CUH2, SEQ ID NO: 8 identifies *Aspergillus sydowii* strain CUH7, and SEQ ID NO: 9 identifies *Aspergillus sydowii* strain CUH8.

36. The method of claim 26, wherein the method comprises amplifying the *Aspergillus* species internal transcribed spacer 1 region using primers comprising at least 15 consecutive nucleotides of at least five of (a), (b), (c), (d), (e), (f), (g) and (g).

37 The method of claim 26, wherein the method comprises amplifying the *Aspergillus* species internal transcribed spacer 1 region using primers comprising at least 15 consecutive nucleotides of all of (a), (b), (c), (d), (e), (f), (g) and (g).

38. An isolated nucleic acid molecule comprising a nucleotide sequence set forth as:  
(a) SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12, or a degenerate variant thereof;  
(b) SEQ ID NO: 13, SEQ ID NO: 14, or a degenerate variant thereof;  
(c) SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, SEQ ID NO: 18, or a degenerate variant thereof; or

(d) SEQ ID NO: 19 or a degenerate variant thereof,  
wherein the nucleotide sequence identifies a member of the genus *Aspergillus* as a member of *flavipes*, *restrictus*, *versicolor*, or *wentii* species.

39. The isolated nucleic acid molecule of claim 38, comprising a nucleotide sequence set forth as:

(a) SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12;  
(b) SEQ ID NO: 13 or SEQ ID NO: 14;  
(c) SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, or SEQ ID NO: 18; or  
(d) SEQ ID NO: 19.

40. The isolated nucleic acid molecule of claim 38, wherein the nucleic acid molecule consists essentially of the nucleotide sequence set forth as (a), (b), (c) or (d).

41. The isolated nucleic acid molecule of claim 38, wherein the degenerate variant has at least 75% sequence identity to the nucleotide sequence of which it is a degenerate variant.

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42. The isolated nucleic acid molecule of claim 38, wherein the degenerate variant has at least 90% sequence identity to the nucleotide sequence of which it is a degenerate variant.

43. The isolated nucleic acid molecule of claim 38, wherein the degenerate variant has at  
5 least 95% sequence identity to the nucleotide sequence of which it is a degenerate variant.

44. The isolated nucleic acid molecule of claim 38, wherein the nucleic acid molecule consists of a sequence that has 100% sequence identity to the nucleotide sequence set forth as:

- 10
- (a) SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12;
  - (b) SEQ ID NO: 13 or SEQ ID NO: 14;
  - (c) SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, SEQ ID NO: 18; or
  - (d) SEQ ID NO: 19.

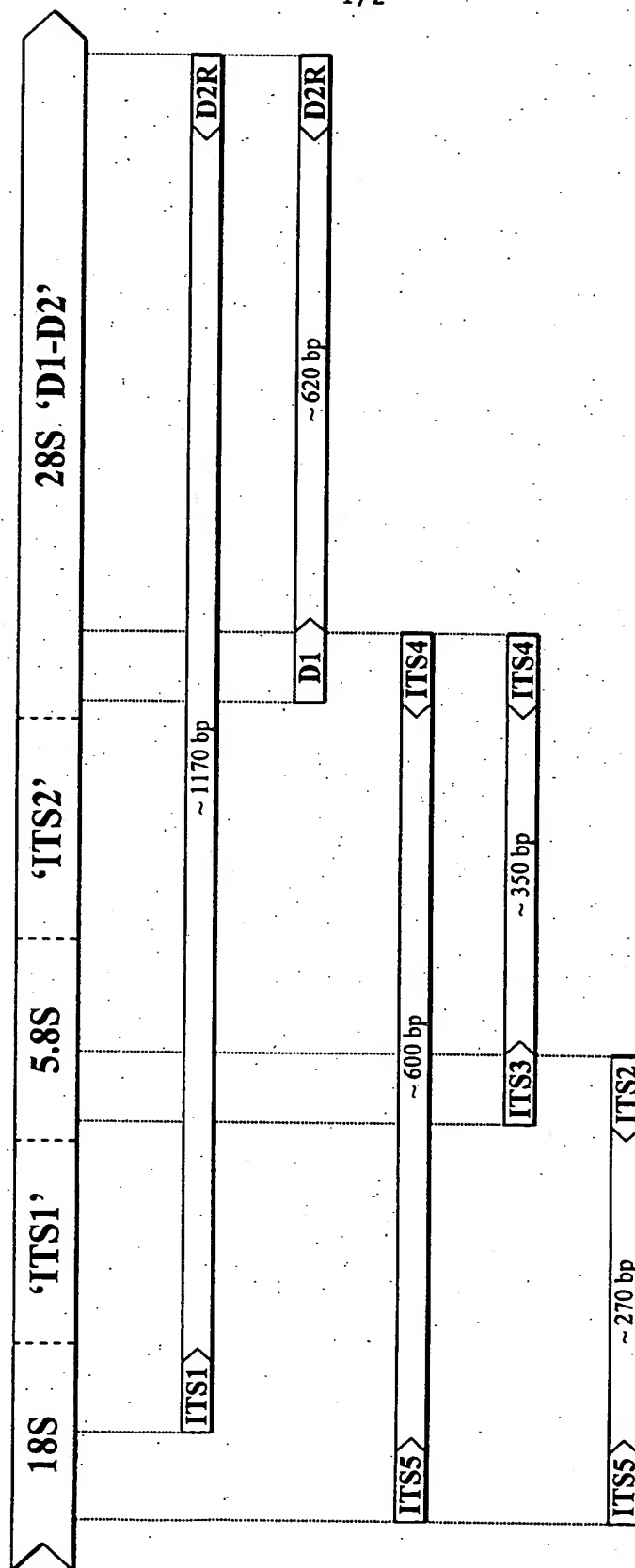


FIG. 1

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A. niger II							
A. flavus	TA	TCA CGA	C	T C	TTA	AT CA	
A. parasiticus	TA	TCA CGA	C	T C	TTA	TT CA	
A. tamarii	TA	TCA CGA	C	T C	TTA	TT CA	
A. flavipes I	A	TCC TG	C	A C	AC	AGCCTC GCT	
A. flavipes II	A	TCC TG	C	A C	AC	AGCCTA GCT	
A. flavipes III	A	TCC TG	C	A C	AC	AGCCTC GCT	
A. candidus	A	TCC TG	C	A C	AC	TT AC	
A. terreus	T	ATG	C	A	T	AGCCT -GCT	
A. chevalieri	C	C	T	TC	T G	TTCTT	
A. restrictus	C	C	C	C	T	TTCTT	
A. fumigatus	A	C	C	C	T	T	CGAC
A. granulatus	A	TCTG CC	CGAG	T	AA CC	T G C T C	
A. ustus I	A	TCTG CCC	CGAG	T	AA CC	T G C C C	
A. ustus II	A	TCTG CCC	CGAG	T	AA CC	T G C T C	
A. ustus III	A	TCTG CCC	CGAG	T	AA CC	T G C C C	
A. ustus IV	A	TCTG CCC	CGAG	T	AA CC	T G C C C	
A. ustus V	A	TCTG CCC	CGAG	T	AA CC	T G C C C	
A. sydowii I	T	CTG CC	GC	AA CC	AA CC	GACCT C C	
A. sydowii II	T	CTG CC	GC	AA CC	AA CC	GACCT C C	
A. versicolor I	T	CTG CC	GC	AA CC	AA CC	GACCT C C	
A. versicolor II	T	CTG CC	GC	AA CC	AA CC	GACCT C C	
A. nidulans I	T	CTG CC	GC	AA CC	AA CC	GACCT C C	
A. nidulans II	T	CTG CC	GC	AA CC	AA CC	GACCT C C	

	120	140	160	180	200	3'
A. niger I	GGGCGCC TCT -GGCCCGCG GCTGTGCGCCCGG AGACCCACAC -GA ACACCTT -CTGAAA GCG -TGCATCTGTA GTT -GATTGAAAT -GC AA -TCA -GTTA					
A. niger II						
A. flavus	CA	C	A C	T	CTA	T C
A. parasiticus	CA	C	A C	T	CTA	T C
A. tamarii	A	C	A C	T	CTA	T C
A. flavipes I	T	C	A C	T	CTA	T C
A. flavipes II	T	C	A C	T	CTA	T C
A. flavipes III	T	C	A C	T	CTA	T C
A. candidus	A	C	A C	T	CTA	T C
A. terreus	A	C	A C	T	CTA	T C
A. chevalieri	T	CTT	G	GT	TT G T A	
A. restrictus	T	CTT	G	GT	TT G T A	
A. fumigatus	A	C	A C	T	CTA	T C
A. granulatus	GCA	A	C	CTCT GT	T C	ATA
A. ustus I	GTA	A	C	CTCT GT	TT	ATA
A. ustus II	GTA	A	C	CTCT GT	TT	ATA
A. ustus III	GTA	A	C	CTCT GT	TT	ATA
A. ustus IV	GCA	A	C	CTCT GT	TT	ATA
A. ustus V	GG CG AA	G	A C	CTCT GT	TT	ATA
A. sydowii I	GGCA	G	TA T	TTCA GC	G T A	ATA
A. sydowii II	GGCA	G	TA T	TTCA GC	G T A	ATA
A. versicolor I	GGCA	G	TA T	TTCA GC	G T A	ATA
A. versicolor II	GGCA	G	TA T	TTCA GC	G T A	ATA
A. nidulans I	GGCA	G	TA T	TTCA GC	G T A	ATA
A. nidulans II	GGCA	G	TA T	TTCA GC	G T A	ATA

FIG. 2

## SEQUENCE LISTING

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THE SECRETARY OF THE DEPARTMENT OF HEALTH AND HUMAN SERVICES, CENTERS  
FOR DISEASE CONTROL AND PREVENTION

Morrison, Christine J.

Hinrikson, Hans Peter

<120> MOLECULAR IDENTIFICATION OF ASPERGILLUS SPECIES

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tccgtaggtg aacctgcgg

19

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gcatcgatga agaacgcagc

20

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<400> 33  
caggtctgcc cctggcag

18

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ccttcttggt taagcctg

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18

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18

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18

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ctgtctttag tgttgtct

18

<210> 62  
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<400> 62  
tcttttagtgt tgtctgag

18

<210> 63  
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<400> 63  
ttagtggtgt ctgagctt

18

<210> 64  
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gtgttgctctg agcttgat

18

<210> 65  
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ttgtctgagc ttgatagc

18

<210> 66  
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<400> 66  
 gagcttgata gcaaacct

18

<210> 67  
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<220>  
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<400> 67  
 cttgatagca aacctatta

19